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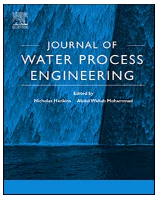

Performance evaluation of 3D rotating anode in electro coagulation reactor: Part I: Effect of impeller

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ABSTRACT

A hopper bottom electro chemical reactor with perforated 3D anode is attempted to avoid commonly encountered problems in conventional electrochemical reactor like short circuiting, development of dead zones, formation of oxide layer on anode surface etc. The RTD experiments and CFD simulations established that the present configuration performs better than commonly used plate electrode electrochemical reactors. The synthetic textile wastewater is treated in the proposed configuration. A higher COD removal efficiency (85.12%), color removal efficiency (97.97%) and low specific energy consumption (0.047 J/mg) are observed vis-à-vis plate electrode electrochemical reactors.

1. Introduction

In current scenario, water consumption and wastewater generation is becoming a cosmic issue in this era of industrial revolution. The conventional technologies presently available are costly and have become inefficient due to their own limitations to treat the wastewater to a desired level. The introduction of electrochemical technologies for the treatment of industrial wastewater is of great influence and readily replacing the conventional treatment technologies. In recent years, various treatment technologies have been used such as advanced electro oxidation, photo oxidation, electro coagulation, electro floatation, etc. [1–6].

The design of electrochemical reactor plays an important role in the process of treatment. It drives the dynamics of the fluid to be treated inside the electrochemical reactor. The effective geometry and design eradicate the issues that come into play with regular electrochemical reactors. The proper design and geometry of the electrochemical reactor helps the fluid to be treated in a uniform fashion leaving no dead zones, short circuiting, channeling and fouling of electrode [7–10]. All the issues can be addressed with efficient mixing inside the electrochemical reactor [11–14].

The residence time distribution (RTD) is an attribute of mixing in the electrochemical reactor. It provides information about the residence of elements inside the reactor. It helps to develop an accurate kinetic model for electrochemical reactor. The RTD also helps to design the reactor with desired fluid dynamics, which helps in scaling up of the reactor [15–20].

In the present work, a reactor configuration with a 3D rotating anode acting as turbulence enhancer is presented to overcome the disadvantages experienced with the usual reactors like fluid channelling/short circuiting, back mixing, formation of dead zones and oxide layer formation on electrode etc., which may lead to loss of process efficiency and higher energy consumption. The 3D anode also acts as an impeller; hence in the following text anode is referred as impeller.

The study is being presented in two parts. The effect of the 3D impeller on the flow dynamics and improvement of yield is presented in this paper. The effect of rotation of 3D anode yielding performance improvement is being presented in second part of this series.

2. Literature review

The considerable amount of experimental and theoretical work has been done on RTD of the electrochemical reactor. Recently; the presence of inlet and outlet condition, presence of impeller and its mixing speed on the efficiency of mixing process have been investigated using RTD [17,21,22]. The mass tracer fraction helps in the study of flow behaviour and exit age distribution curves of parallel plate electrochemical reactor using single and two/three tank in series RTD model [23–25]. A significant improvement in mixing performance of an electrochemical reactor can be achieved by adding a draft tube at low impeller clearance [26].

The velocity, pressure and vector distribution in a chemical reactor

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has been easily predicted by computational fluid dynamics (CFD) which has improved the understanding of RTD [27,28]. The available CFD tools are extensively used to simulate the velocity distributions and fluid dynamics of various electrochemical reactors [7,29,30]. The CFD predicted RTD using k-ε model given similar results as measured experimentally for baffled reactor [31]. The RTD of fluid in electrochemical reactor has been analysed using Eulerian particle tracking and Lagrangian particle tracking method. The Eulerian approach comes out to be significant than Lagrangian approach [32]. The effect of flow rates, inlet/outlet locations, batch blend time to mean residence time ratio on mixing performance of the electrochemical reactor is also studied at fully turbulent regime. Whereas; mixing studies are done to find concentration of tracer around impeller and in fluid region both using CFD and RTD [33,34].

Mixing is greatly affected by hydrodynamic behaviour of the fluid inside the electrochemical reactor. The mixing behaviour of an electrochemical reactor using KCl as a tracer is studied and age distribution function, *I(θ)* is calculated preceded by measurement of concentration at exit stream [17,35].

3. Material and methods

In present work, the fluid dynamics of the reactor in absence and presence of the impeller is studied. This provides the insight of the change in fluid dynamics behavior after introduction of the impeller in the reactor. Both outlets are kept in open condition for CFD analysis. The flow rates used in this study are 5, 15, 30, 60, 90 and 120 lph. The CFD output of 5, 60 and 120 lph (minimum, mid-point and maximum) are presented here due to space constraint. The pressure profile, velocity vector, magnitude profile, mean turbulent intensity, mixing time and tracer mass fraction are studied through CFD, and the discussion is made on the outcome of CFD results.

All the RTD experiments are carried out with raw water as an electrolyte and NaCl as a tracer under room conditions. The tracer mass fraction is done with 6.5 M NaCl solution with the water analyzed experimentally and using CFD simulations. Raw water is fed into the proposed electrochemical reactor at different flow rates (5, 15, 30, 60, 90 and 120 l/h) from the reservoir of raw water. For each cycle, 10 ml of tracer with similar properties of water, is introduced into the stream of proposed electrochemical reactor in the form of pulse input and time is noted for the injection. The electrical conductivity of the tracer + raw water from the outlet is measured at equal time interval of 30 s. The experiment ended when the electrical conductivity value decreases to the normal raw water conductivity levels.

3.1. Geometry specification of reactor

A conical hopper bottom vessel used as a reactor with a 3D rotating cylindrical impeller acting as an anode is shown schematically in Fig. 1. The 3D rotating cylindrical impeller is designed to facilitate better mixing during the electrolysis process. The additional advantage it would offer is to prevent oxide layer formation, which in turn would slow down the fouling of electrode. The surface of electrode is kept perforated to further improve the mixing phenomenon for better yield of the process.

The working fluid is a water-dye solution where removal of dye from water is studied. The tracer mass fraction is done with a 6.5 M NaCl solution injected in a pulse input method. The analysis is then verified by CFD using experimental RTD data obtained from the experiments. The study with the presence of impeller and without impeller is performed to analyze the effect of the impeller on the reactor performance. The dimensions of the reactor configuration are presented in Table 1.

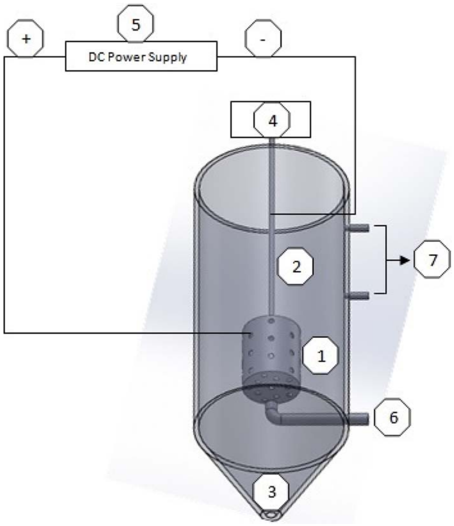

Fig. 1. Geometry of Proposed Reactor. 1) 3D perforated cylindrical impeller (anode). 2) Rod (cathode). 3) Conical Hopper Bottom for Sludge collection. 4) Mechanical stirrer. 5) DC Power Supply Unit 6) Inlet for wastewater. 7) Outlet for treated water.

Table 1
Dimensions of the Reactor Configuration with electrode.

Reactor Volume	4.0 l
Diameter of Cathode	1 cm
Inside Diameter of the Anode	4 cm
Thickness of the Anode	0.5 cm
Area of the Anode	254.82 cm^2
Inlet and Outlet Diameter	0.5 cm

4. Results and discussions

4.1. Pressure distribution

Pressure distribution profile of the reactor provides substantial information regarding the fluid dynamics behaviour in terms of pressure drop. The parts of the reactor where pressure drop is negative implies the low mixing zones created due to short circuiting/channelling or due to low inlet fluid velocity. Uniform pressure distribution resembles the proper mixing inside the reactor and reduces the chances of short circuiting/channelling.

The pressure contours for the flow rates of 5, 60 and 120 lph in the absence and presence of impeller in the reactor are presented in Fig. 2. For the flow rate of 5 lph, Fig. 2(a), the pressure is increasing towards the bottom of the reactor. There is a negative pressure zone created around the inlet which means that the pressure of this zone is less than the other parts of the reactor which imply that at low flow rate the fluid moves away from the inlet zone and creates a low-pressure contour. The bottom zone of the reactor indicates a slightly high pressure index than the other parts of the reactor. The pressure near the outlet shows mid pressure index implying releases of fluid though the outlet. For the same flow rate of 5 lph when the impeller is introduced inside the reactor, Fig. 2(d), the pressure profile changes significantly indicating better distribution of pressure all along the reactor. Different pressure contours are present around the impeller which indicates that the introduction of the impeller has significantly changed the dynamics of the reactor, as there is no low pressure zone present inside the reactor in this case. The reactor shows a uniform distribution of pressure zone from bottom to top of the reactor. The impeller in accordance with pressure index can be divided into right and left half as can be clearly seen in Fig. 2(d). The pressure index shows high pressure zones in the right part of the impeller and slightly low pressure zone on the left part of the impeller. This confirms the movement of fluid from right to left of